TACHOMETERS

FOR

AIRPLANE ENGINES

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The following publication, entitled "Tachometers for Airplane Engines," is published for the information and guidance of all concerned.

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BY ORDER OF THE SECRETARY OF WAR:

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TACHOMETERS.

Use.

The purpose of the tachometer is to indicate the speed of revolution of the crank shaft of the engine. This is expressed in revolutions per minute (R.P.M.). This also gives the speed of the propeller, except in the case of geared engines, in which case the R.P.M. of the propeller can be easily computed, since the reduction ratio is always known, generally 3:5.

The principal use of the tachometer is as a detector of engine trouble, which generally results in a decrease of speed. The tachometer, therefore, shows at all times quickly and surely whether or not the engine is working properly. This information is vital, since an airplane depends on its engine, not only for propulsion, but also for its support in the air and its climbing ability. In testing an engine before leaving the ground the tachometer reading should be carefully noted. If the R.P.M. is not sufficient the pilot may not be able to clear the buildings or other obstacles of the field and a "smash" results. In the lower powered training airplanes a decrease of 50 R.P.M. should be taken as a warning of serious engine trouble.

When once in the air a pilot can generally tell by the "feel of the ship" whether or not the engine speed is sufficient. But still the tachometer reading is a valuable guide to the performance of the engine and will give warning of serious failure.

In the second place a tachometer is needed in any kind of performance test of an engine, whether block, dynamometer, or a flight test. When once the speed of greatest efficiency is determined the tachometer reading enables the pilot to hold this.

A third use of the tachometer is in cross-country flying. On a long trip the wear and tear on the engine can be considerably reduced by throttling down to a somewhat lower speed than the maximum obtainable. The best speed must be determined by experiment with any particular type of airplane. It is somewhat greater than the minimum speed without loss of altitude. When once it has been determined the tachometer will enable the pilot to set the engine readily at this speed without having to try the experiment every time.

2. Construction.

Four types of tachometers have been adopted by the Air Service.

(1) Type A, manufactured by the National Cash Register Co.
(2) Type B, manufactured by the Johns-Manville Co.
(3) Type C, manufactured by the Van Sicklen Co.
(4) The Victometer, manufactured by the Jones Motrolo Co.

These are shown in Figure I. Types A and C are chronometric, while type B and the Victometer are centrifugal in principle. The latter will be described first, as the design is simpler.

TYPE B, JOHNS-MANVILLE TACHOMETER.

The scale of this instrument extends over only about 200° of the circumference of the dial. The range is from 500 R.P.M. to 2,500 R.P.M., and the smallest division is 50 R.P.M. Except when the engine is running very steadily, the speed can not be read closer than 25 R.P.M. The internal mechanism is illustrated by Figure II. There is a vertical shaft *a* mounted on ball bearings, which is driven directly by the flexible shaft coming from the motor. On this shaft are three weights *b*, each mounted on a hinged arm, which is pivoted at the upper end to a spider *c* fixed to the shaft, and at the lower end to a grooved collar *d*, sliding on the shaft. When the shaft is rotated, under the action of the centrifugal force brought into play, these weights move out and raise the sliding collar. The upward motion is opposed by a helical spring around the shaft. So for a given speed of rotation the collar is moved up to a certain position where the force of compression of the spring balances the effect of the centrifugal force of the weights. The upward motion of the sliding collar, which is small (one-fourth to three-eighths inch), is magnified and changed to the motion of the pointer by the *indicating train*, consisting of a lever *e*, a sector gear *f*, and a pinion *g*; *e* and *f* are mounted on the same shaft, and *g* is on the pointer shaft. A hairspring on this same shaft takes up the back lash between *f* and *g*. Since the centrifugal force varies as the square of the velocity and the force of compression of the spring only as the first power of the distance of compression, the motion of the pointer will not be uniform throughout the scale, but greater in the upper portion, unless some provision is made to equalize the motion. In this instrument this is done by setting the lever *e* at such an angle that at low speeds the magnifying ratio of the motion will be greater than at high speeds. So with this arrangement a fairly uniform scale is obtained. However, a defect of this instrument is the fact

FIG. I.—TACHOMETERS.

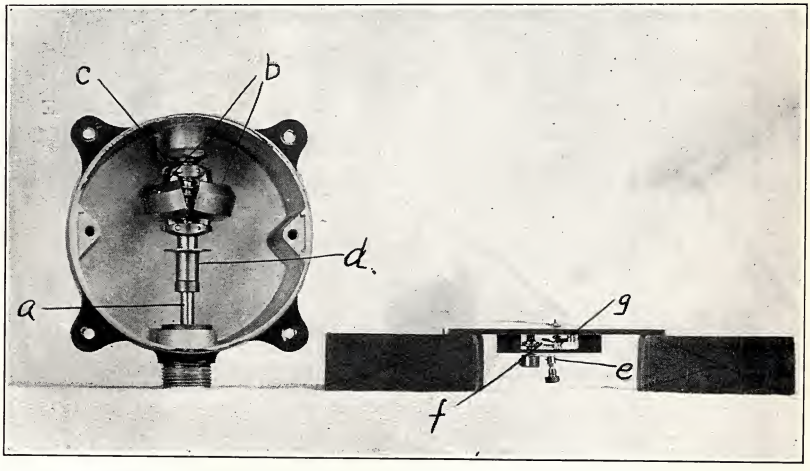

FIG. II.—MECHANISM OF CENTRIFUGAL TACHOMETER.

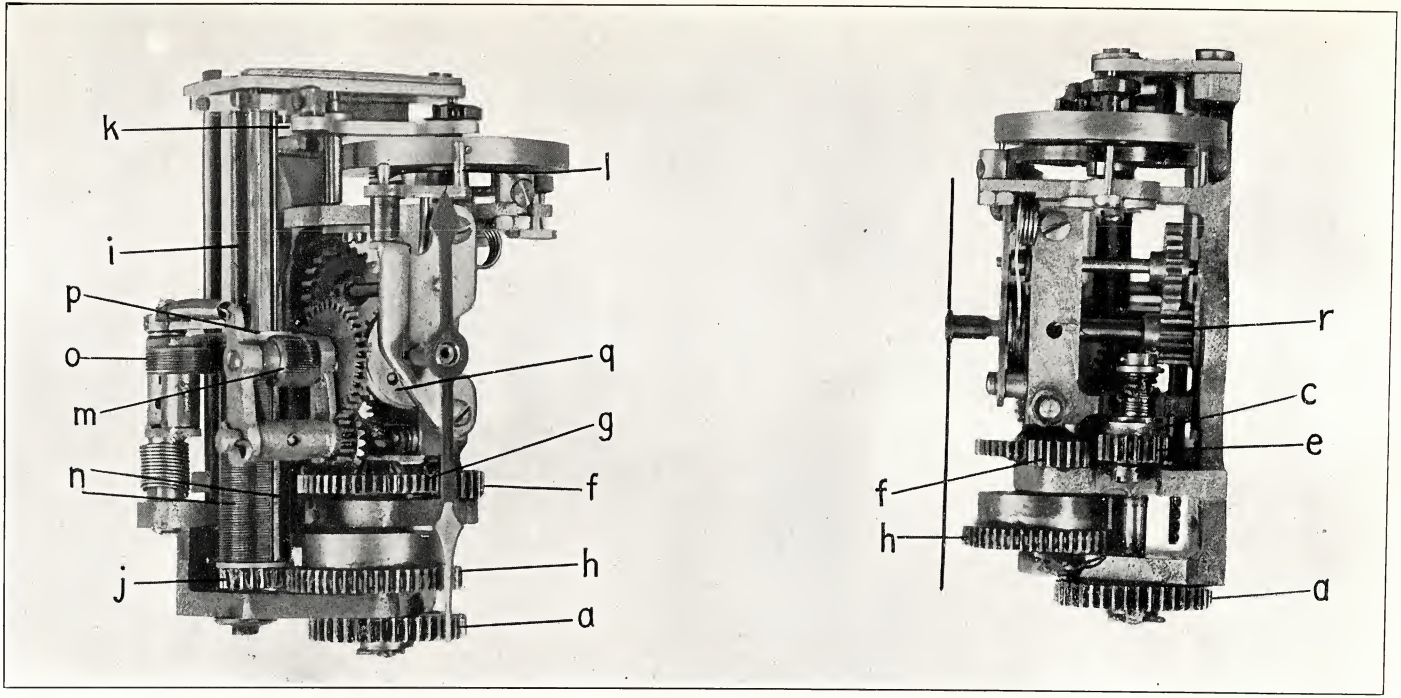

FIG. III.—MECHANISM OF CHRONOMETRIC TACHOMETER, TYPE A.

that only a little more than half the circumference of the dial is utilized in the scale.

VICTOMETER.

The range of the scale of this instrument is the same as type B, but it covers the entire circumference of the dial and consequently is more open. The smallest divisions are 20 R.P.M. The general principle of operation is the same as in type B, but the weights of the governor are lighter and are run at twice the indicated speed, while in type B the governor speed and indicated speed are the same.

CHRONOMETRIC TACHOMETER, TYPE A.

The principle of the chronometric tachometer is entirely different from the centrifugal. The speed of rotation is measured by the motion of a gear, or a toothed rack, in equal intervals of time, one or two seconds, during which it is connected with the main driving shaft. At the end of each interval the motion of the gear, or rack, is interrupted by the action of a watch or clock escapement and the motion begins anew. Since the time intervals are equal, the motion during each interval is proportional to the speed of the driving shaft, and therefore measures that speed. The motion of the gear or rack is shown by the pointer moving over the scale.

Type A is an exact copy of the French instrument "Tel," manufactured by the Hasler Telegraphic Works, Berne, Switzerland. The mechanism, shown in Figure III, may be divided into four systems, (1) driving, (2) escapement, (3) counting, and (4) indicating. The *driving system* consists of the main drive gear *a*, mounted on an arbor which also carries the gear *b* and the rocker arm *c;* gears *d* and *e* on rocker arm *c;* gear *f* pivoted on a stud fastened to the frame; and the gear *g* fastened to the spring barrel shaft. Gear *a* is engaged by and driven by the pinion of the case drive spindle. Gears *b*, *d*, *e*, and *f*, and the rocker arm *c*, make up the reversing unit, the function of which is to give gear *g* always the same direction of rotation, for either direction of rotation of the driving shaft. Gear *b* has the same speed of rotation as *a* and continuously turns *d* and *e* in opposite directions. When *a* rotates clockwise *d* engages *g*, and *e* and *f* are idle; when *a* rotates counter-clockwise *c* is turned slightly, due to friction between *c* and the arbor, until *e* engages *f*, which is continuously engaged with *g* and *d* idles.

The *escapement system* consists of the spring barrel *h*, the shaft *i* with gear *j* at the lower end, and the double-roller escapement *k*. The spring barrel *b* is mounted on the same shaft as gear *g*, but free to turn on it. In *b* is a spring similar to a watch mainspring, the inner end of which is fastened to the shaft, and the outer end is free.

The spring barrel is driven by the friction between the spring and the barrel. As the shaft turns, the spring is wound up to a certain tension, at which the free end begins slipping in the barrel. In this way a constant torque is applied to the spring barrel, which is transmitted by *j* to the shaft *i*. The action of the escapement *k* keeps *i* turning at a constant rate, once in three seconds, for all speeds of the driving shaft. To facilitate the starting of the escapement there is an auxiliary device which stops it off-center with tension on the escapement spring and also prevents the mainspring from unwinding completely. This action occurs as the pointer returns to zero; a pin *l* falls automatically, engaging a stud on the rim of the balance wheel.

In the *counting system* a gear train connects *g* of the driving system with a fine-toothed pinion *m*, which engages, one at a time, three racks *n* on shaft *i*. These three racks, each in the form of an arc of 120 degrees, surround the shaft *i*. Their zero position is against *j*, to which position they are brought by the action of a helical-control spring, in a groove under each rack. As *i* rotates, each rack is engaged by *m* for one second and moved up along *i*. Just as the rack leaves *m* it is engaged by a cylindrical pawl *o* and held in this advanced position for one second. It is then released and returns to its position against *j* by the action of its helical-control spring.

The *indicating system* consists of a collar *p* encircling the shaft *i*, which is fastened rigidly to a coarse-toothed rack, which in turn engages a pinion *r* on the pointer shaft. As the racks *n* are moved along *i* the collar *p* and its rack are moved the same amount and thus the pointer shaft is turned. A control spring opposes the motion of *p* and takes up the back lash between the rack and the pinion. Since the pinion *m* is connected through a gear train of the counting system and another gear train of the driving system to the *main drive gear a*, its speed of rotation is proportional to the speed of the driving shaft; and hence the distance each of the racks *n* is moved is proportional to the driving speed for that second, and each rack is held by the pawl *o* for one second at a distance from the zero position of the racks proportional to the driving speed during the preceding second. Hence the displacement of the collar *p* and the position of the pointer on the dial is for each second proportional to the speed during the preceding second.

Let us suppose the tachometer is just beginning to operate. The rack under the pinion *m*, which we call rack No. 1, is moved up for one second. This carries the pointer from 0 around the dial a distance proportional to the total number of turns of the driving shaft in one second. This is indicated on the dial as a certain R.P.M. For the next second rack No. 1 is held in the same place on the shaft by *o* while rack No. 2 is moved up. If the total number of turns of the

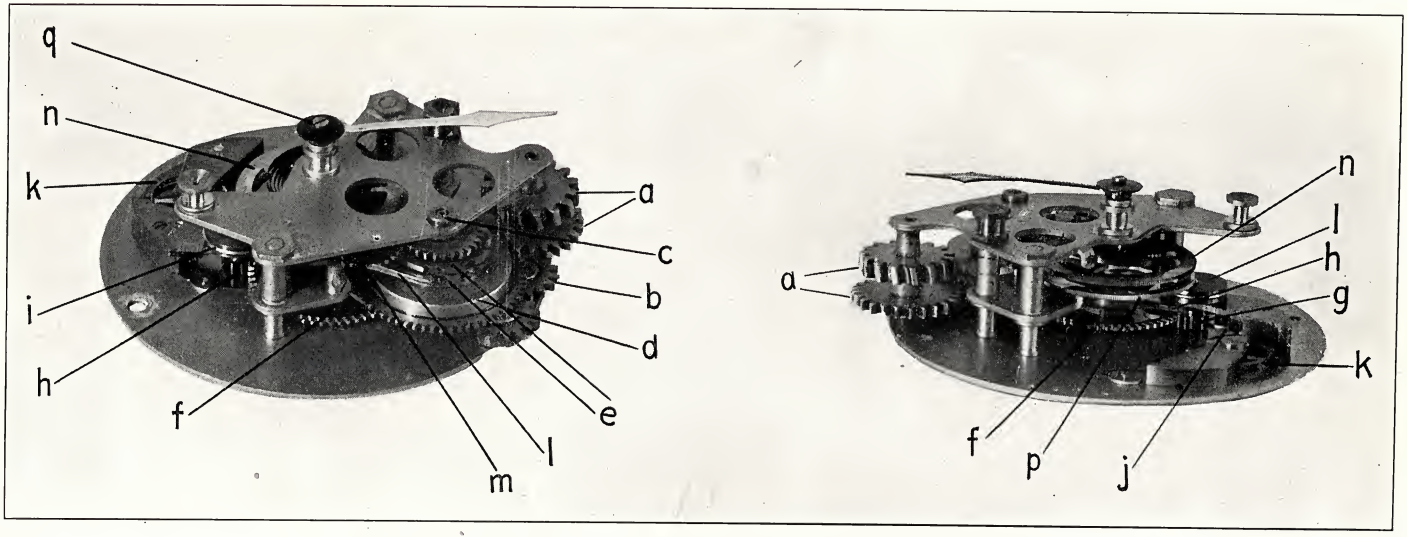

FIG. IV.—MECHANISM OF CHRONOMETRIC TACHOMETER, TYPE C.

driving shaft is *greater* than during the first second the collar *p*, and consequently the pointer, is moved further along, and a higher R.P.M. is indicated. But if the total number of turns of the driving shaft is *less* than during the first second, as rack No. 1 is released by *o* and rack No. 2 is engaged, the collar slips back to the position of rack No. 2, and the pointer indicates a smaller R.P.M. So that every second a new R.P.M. is indicated if there is a change in speed of the engine and the driving shaft during that time.

A loose pin-and-hole connection *q* in the pointer shaft serves to remove fluctuations of the pointer due to imperfect meshing of the rack and pinion of the pointer shaft. This, however, is a source of inaccuracy which may amount to about 20 R.P.M.

Many minor details of construction and operation have been omitted in this description, and can be best observed by removing the dial of the instrument and examining while the tachometer is in operation.

TYPE C, VAN SICKLEN TACHOMETER.

Figure IV illustrates the mechanism of the tachometer. Since the principles of operation are generally the same as for type A, only a brief description will be given, and the reader is referred to the Van Sicklen Instruction Book for more detailed information. As in type A, the mechanism may be considered to consist of four systems: (1) Driving, (2) escapement, (3) counting, (4) indicating.

The *driving system* consists of the two gears of the idler unit *a*, two gears of the reversing unit *b*, and two gears, one at the top and one at the bottom, of the spring barrel shaft *c*. The top gear of *a* is driven by the worm of the case drive, and the lower gear transmits the motion to the first gear of the reversing unit *b*. The reversing unit consists of two gears mounted on a swivel plate which so operates that *c* is always driven in the same direction for either direction of rotation of the driving shaft.

The *escapement system* consists of the spring barrel *d*, three synchronizing cams *e*, an intermediate unit *f* with two gears, the fly unit composed of the fly pinion *g*, fly *h* and friction disk *i*, the watch escapement *j*, and the watch balance *k*. The spring barrel *d* is driven by a constant torque through the action of the friction mainspring inside as in the case of the type A tachometer. The cams *e* are fastened rigidly to *d* and idle on *c*. The motive power of the spring barrel is transmitted through *f*, *g*, and *h* to the watch escapement, which has a reciprocal action on *d* and *e*, so that the speed of rotation of the latter is uniform for all speeds of the driving shaft. The operations of the counting and indicating systems which are controlled directly by the cams thus occur in a definite time order.

The *counting system* consists of a time lever *l* which is a rocker arm carrying a gear *m* to the underside of which is fastened a fine-toothed pinion, the counter gear *n*, and the upper pawl *o*. Gear *m* is driven by the top gear of the spring barrel shaft *c*, and the fine-toothed pinion attached to it engages *n*. By the action of the middle cam of *e* the time lever is rocked so that the pinion engages *n* for one second and then is thrown out for one second. Since *m* is connected through a gear train to *a* its speed is proportional to the speed of the driving shaft and during the second that *n* is engaged by *m* it is turned through an arc proportional to the speed of the driving shaft for that second. During the next succeeding second *n* is held in its advanced position by the pawl *o*, which is operated by the upper cam. At the end of this second *o* releases *n* before the pinion engages it, and *n* is returned to its zero position by the action of a spiral control spring.

The *indicating system* consists of the pointer gear *p*, similar to *n* and below it, the pointer spindle *q*, the lower pawl *r*, and two stop arms between *n* and *p*. Gear *n* idles on *q*, while *p* is fastened to it and turns just as *p* does. When *n* is turned up by the pinion of the time lever, by the action of the stop pins on *n* and *p* and the two stop arms, *p* is turned to the same advanced position. Ratchet teeth on *p* permit its being turned while *r* engages it. At the same instant that *n* is locked by *o*, *r* is momentarily thrown out by the action of the lower cam, so that the pointer gear will fall back by the action of its control spring to the new position of *n*, providing there has been a decrease in speed.

We may now consider the action of the tachometer for one cycle. During the first second of operation the counter gear is turned up in a clockwise direction through an arc proportional to the total number of turns of the driving shaft, and carries with it the pointer gear and pointer, which indicates on the dial a certain R.P.M. At the end of the first second the time lever *l* is thrown out and the pawl *o* engages the counter gear *n* holding it to this position. At the same instant the bottom pawl *r* is thrown out for about one-fifth of a second and then engages the pointer gear again. At the end of the second the top pawl *o* releases the counter gear, which is carried back by its control spring to its zero position. During the third second the counter gear is again carried forward. If the total number of revolutions of the driving shaft is *greater* than during the first second, the pointer gear is carried forward to a new position, and the action is the same as during the first and second seconds. But if the total number of revolutions of the driving shaft is *less* than during the first second, the action is somewhat different. At the end of the third second the time lever is thrown out, the top pawl *o* engages the counter gear and holds it in its new position during the

fourth second, and the bottom pawl *r* releases the pointer gear for a short interval, during which it is carried back by a spring to the position of the counter gear where it is again locked by the bottom pawl and held during the remainder of the fourth second, and the first second of the succeeding cycle. Thus we see that for every two-second period a new R.P.M. is indicated on the dial, if there has been a change in speed during that interval. However, there is this difference between the action of the types A and C: In type A the counting mechanism is carried forward for periods of one second each and during every successive period, while in type C it is carried forward for periods of one second each and during every alternate second.

3. Installation.

The tachometer is driven by a flexible shaft (see specification No. 27018–B), which is coupled to some rotating part of the motor. With the Curtis OX and the Hispano-Suiza motors it is coupled direct to the cam shaft, which has one-half crank shaft speed. With the Liberty motor the tachometer connection is driven by the generator shaft, also at one-half crank shaft speed. Tachometers types A and C and Victometer are so designed that the case drive should be one-half crank shaft speed, so no special adapter is needed between the motor and tachometer. But the type B tachometer is designed to be driven at crank shaft speed, so that a 2:1 step-up adapter must be used, and the flexible shaft is driven at crank shaft speed. This adapter should be furnished with each type B instrument.

With the Le Rhone rotary motor, which is used with some advanced training airplanes, the tachometer shaft is driven from the oil pump shaft. This latter has a speed of nine-fifths the motor speed, so that a special adapter having a five-eighteenths reduction should be used, in order to give the tachometer shaft a speed of one-half engine speed.

The following general instructions should be followed:

(1) The proper length shaft should be used. A too long shaft will require unnecessary bends and undue friction in the shaft casing. There should be no bend of less than 6-inch radius.

(2) The tachometer should be securely fastened to the instrument board, using the screws, nuts, and lock washers furnished with the instrument.

(3) The shaft should be properly lubricated with the best grade of white vaseline, and care taken that it rotates freely in the casing.

(4) Couple the shaft to the *tachometer* before the engine end is connected, as otherwise the spindle of the shaft may slip out of the engine coupling. In making the coupling see that the engaging square on the shaft and the driving spindle of the tachometer are clean. Put a drop of oil on the threads and tighten the octagon nut onto the tachometer.

(5) Couple the engine end after the shaft is in place and connected to the tachometer. Observe carefully that the shaft is the right length. If too short the driving end may work out of the engine coupling; if too long the shaft will bind against the casing. In either case the shaft should be discarded and a new one tried.

(6) In case the tachometer fails to operate, examine *first* the shaft. If this is all right, send the tachometer to the *instrument* repair shop and install a new one. The specifications require that the maximum error be not greater than 20 R.P.M., and in the chronometric types the error generally is much less than this.

4. Choice of Instrument.

Extensive tests made at the Bureau of Standards on various types and makes of tachometers have shown that the chronometric types are much more reliable and satisfactory instruments than the centrifugal. In the following particulars the chronometric types are superior: (1) There is no difference between readings taken as the speed is increasing and readings taken as the speed is decreasing. In the centrifugal this difference averages about 40 R.P.M. (2) In new instruments the mean error is considerably less in the chronometric than the centrifugal. (3) After 150 hours' running under the vibration the mean error of the centrifugal is about eight times greater than that of the chronometric. (4) The temperature effect in the chronometric is less than in the centrifugal.

In view of the above, types A and C should be specified in preference to type B, and type C is somewhat more reliable than type A.

Note.—Some other types of tachometers found on some older airplanes are described in another pamphlet.

References.

B. A. P. Specification No. 27012–C.
P. E. D. Drawing No. 0–K–32,
Aeronautical Instruments Circular No. 28, and
Report on Average Errors of Tachometers, Oct. 21, 1918, Bureau of Standards.

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